The effects of a higher sea level on the coasts of Port Phillip Bay

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Abstract
Sea level may rise in Port Phillip Bay in response to global warming and higher ocean levels, while channel deepening at the entrance will produce higher high tides. A rising sea level will lead to submergence and increased erosion on the bay shores, and the eventual disappearance of Mud Islands. The response to submergence should be landfilling to raise low lying areas, while increased coastal erosion should be countered by renourishment of protective beaches rather than the building of sea walls or boulder ramparts. (*The Victorian Naturalist* **123** (1), 49-54)

Introduction

Port Phillip Bay formed about 6 000 years ago during the world-wide sea level rise known as the Holocene Marine Transgression. The sea then flooded into a basin, the Port Phillip Sunkland (Keble 1946), through a narrow gap in the coastal fringe of Pleistocene dune calcarenite that forms the Nepean Peninsula to the east and the Point Lonsdale foreland to the west. This entrance, known as Port Phillip Heads, is 3.2 km wide at high tides.

There had been previous Port Phillip Bays during high sea level phases of the Pleistocene, and at first the submergence revived the outlines of an earlier bay, but there were soon modifications (Bird 1993a). Cliffs were cut back, and sand eroded from them formed beaches that extended around much of the 260 km coastline. Salt marshes and some mangroves occupied sheltered areas such as Swan Bay, the Yarra estuary and other smaller inlets. It is thought that the sea briefly attained a level a metre or so higher than at present, then fell back, leaving some emerged beaches and resulting in some of the cliffs being degraded to vegetated bluffs (Gill 1950, Bowler 1966).

Evidence from the earliest maps and charts, compiled in the nineteenth century, indicates that the coastline was beach-fringed, with several cliffy sectors and local salt marshes and mangroves. Much of this natural coastline persisted on aerial photographs taken in the 1930s and 1940s, but there had been changes associated with the development of the Port of Melbourne in the Yarra estuary, the construction of harbours and the building of protective structures (mainly wooden walls and groynes) on some eroding sectors (Bird 1988a).

The beaches of Port Phillip Bay were supplied mainly with sand and some gravel derived from eroding cliffs and shore outcrops, with some sand and shelly material swept in from the sea floor during the Holocene marine transgression. Shelly debris is still delivered by gentle wave action in relatively calm weather (Bird 1988b).

Beaches are eroded by storm waves that produce a weak swash and strong backwash, and restored by gentle wave action in subsequent calmer weather. Beach sediment is also moved alongshore when waves arrive at an angle to the shoreline. In winter, wave action in Port Phillip Bay is dominated by winds from the west and north-west which generate southward drifting on the east coast, while, in summer, winds from south-west and south move beach material northward. In consequence, beaches between Port Melbourne and Mount Martha become wider at their northern ends and narrower at their southern ends during the summer, a pattern that is reversed in the winter months.

These alternations complicate the assessment of beach changes but, when the present patterns are compared with those seen on aerial photographs taken in the 1940s, it is evident that beaches have been depleted. Their width at high tide has diminished, and they are generally steeper in profile than they were before 1945. Depletion has been largely due to the building of sea walls and rock revetments that have halted cliff erosion and thus the supply of sand to beaches. In addition the reflection of

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waves by these structures has scoured away the beach, removing sand to the sea floor. Beaches that have escaped erosion are those where sand has accumulated beside or behind harbour structures, as at Sandringham, Middle Brighton and Queenscliff, in each case with depletion of adjacent beaches (Bird 1993a).

Some beaches have been artificially restored, and on the north-east coast of Port Phillip Bay the existing beaches are largely those that were renourished by dumping sand in the 1970s to 1990s (Bird 1990). A renourished beach can be effective in halting cliff erosion, as has been shown on the coast south of Quiet Corner, Black Rock and north of Red Bluff, Sandringham. Renourished beaches maintain acceptable coastal scenery and provide a valuable recreational resource, in contrast to the ugliness of sea walls and rock revetments and the damage that follows their construction. Regrettably, there are still schemes to build or extend sea walls and rock revetments, even though it is clear that these result in beach depletion.

The present coastline of Port Phillip Bay is thus far from natural. It is unstable, and erosion is prevalent. Beaches that have been renourished are diminishing (being subject to the same processes that depleted their natural predecessors), and will have to be restored again in the future (like sea walls, they require maintenance, particularly after storm damage). Even with the sea at its present level and no change in climate the beaches of Port Phillip Bay will continue to diminish, and it is likely that the only beaches still present a century hence will be those that have been artificially renourished.

Causes of a rising sea level

Sea level could rise in Port Phillip Bay if there was subsidence of the land, which has occurred in the geological past within the Port Phillip Sunkland. It could rise if the general level of the oceans rose, because this would be transmitted into Port Phillip Bay. Alternatively, it could rise if the entrance at Port Phillip Heads was substantially enlarged, allowing more water to flow in on rising tides. Sea level can be raised temporarily by storm surges or tsunamis.

The Port Phillip Sunkland has been relatively stable, although earthquakes have occurred along bordering fault lines, particularly Selwyn Fault, which runs down the east coast of the bay from Frankston past Mornington to Dromana and across the Nepean Peninsula to the western side of Cape Schanck (Keble 1950). An earthquake occurred on this fault at Mornington in 1932, and there have been several lesser tremors, but no evidence that these tectonic movements generated tsunamis within the bay. Although tectonic subsidence could occur, leading to a rise of sea level relative to the land in Port Phillip Bay, the risk appears to be slight.

Global Warming and sea level rise

Monitoring of the composition of the Earth's atmosphere, which began in the International Geophysical Year (1957), has shown increases in carbon dioxide, methane and other gases that are known to increase the opaqueness of the atmosphere and thereby reduce the outflow of reflected solar heating from the Earth's surface. This is known as the Greenhouse Effect, and the consequent global warming is expected to cause a world-wide sea level rise, due to thermal expansion of the oceans and increasing inflow of water from the melting of snowfields and glaciers (Pearman 1988). In 2001 the Intergovernmental Panel on Climate Change estimated that global sea level would rise up to 30 centimetres by 2040 and up to 88 centimetres by the year 2100 (Church *et al.* 2001).

Analyses of long-term tide gauge records from coastal stations around the world has shown that over 70% of them show a rise in mean sea level, and it is widely believed that global mean sea level is rising at 1-2 mm/year. However, this is by no means uniform. Satellite sensing has shown that the ocean surface is bumpy and variable; some coastal land areas are rising (sea level falling) while others are subsiding (sea level rising); and the global distribution of reliable tide gauge records is patchy. Evidence from the Point Lonsdale and Williamstown tide gauges may not be reliable because modifications have been made, but it appears that mean sea level in Port Phillip Bay is much the same as it was a century ago (Mackenzie 1939, Bird

1993b). It will be some time before a global sea level rise becomes certain, but if it does sea level within Port Phillip Bay will rise accordingly.

Effects of a rising sea level

In general terms a rising sea level will transgress across the existing intertidal zone, submerging shore platforms and salt marshes as the levels of high and low tide increase around Port Phillip Bay. Mud Islands, surmounting the broad shoals in the southern part of the bay, consist of sandy beaches and dunes encircling a salt marsh, and are likely to be quickly reduced by erosion and submergence. The mouths of inflowing creeks and rivers such as the Yarra and the Werribee will become wider and deeper as high tides attain augmented levels. Nearshore water will deepen, allowing larger waves to break on the shore, intensifying erosion of cliffs and beaches. Where the cliffs are in hard rock, such as the granodiorite of Mount Martha, erosion will be slight as the sea rises, but the soft clay and sandstone cliffs of the Bellarine Peninsula and the north-eastern coast between Sandringham and Balcombe Bay are likely to be cut back more rapidly as wave attack reaches higher levels. Low-lying areas, particularly along the west coast of the bay, will be submerged unless sea walls are built to keep the sea out, or their levels raised by dumping land fill. Organisms that occupy specific intertidal zones will migrate upward on cliffs and shore structures such as sea walls and breakwaters and landward if there are suitable backshore habitats. Such habitats will not be available on much of the bay coastline because of built structures, notably sea walls, and the existing intertidal ecology zones will be squeezed as the habitats become narrower, or disappear.

Erosion has become widespread on coasts where sea level has risen because of coastal land subsidence, due to tectonic activity, as in southern England. Similar erosion has occurred where the coast has subsided as the result of extracting oil, as in southern California, or groundwater, as on the northern coast of the Gulf of Thailand (Bird 1993b). The seaward fringes of salt marshes in the Lagoon of Venice, where sea level is rising because of coastal subsidence, are cliffed and are eroding rapidly.

Beach erosion is extensive on subsiding coasts. The Bruun Rule states that as sea level rises the beach profile is re-shaped, with erosion of the upper beach and withdrawal of sediment to the adjacent sea floor (Bruun 1962). If a sea level rise is followed by a phase of stability the beach profile will be restored at a higher level (Figure 1). There are problems with the Bruun Rule because it assumes that the beach profile was initially in equilibrium, neither gaining nor losing sediment, and that the sea level rise is a specific event, followed by stability (Bird 2001). As has been noted, the beaches of Port Phillip Bay are already eroding, and the prospect is that global warming will lead to a continuing sea level rise. On subsiding coasts there is no doubt that as sea level rises beaches are eroded and sand transferred to the sea floor. Analyses of erosion rates when sea level rises around the Great Lakes in North America indicates that each centimetre of sea level rise results in a metre of beach recession (Schwartz 1967). The predicted rise of sea level could therefore result in up to 30 metres of recession on beaches bordering Port Phillip Bay. At high tide most of the beaches are narrower than this, so they will disappear by 2040 unless they have been artificially renourished.

Storm events

There have been many storms in Port Phillip Bay, and at the end of November 1934 there was a major storm surge. A combination of heavy rainfall and river flooding, low barometric pressure and southerly gales raised high tide water level in the bay by as much as a metre. This caused extensive flooding, rapid erosion of cliffs cut in soft clay and sandstone on the east coast of the bay, and erosion of beaches. There was extensive structural damage at sites along the north and east coast of the bay. The sea level rise was only temporary, and within a week Port Phillip Bay was back to its normal level. In this and other storms in Port Phillip Bay there was severe beach erosion, and sand was withdrawn to form sand bars just offshore, but in subsequent calmer weather much of this sediment moved back on to the beach, restoring the transverse profile.

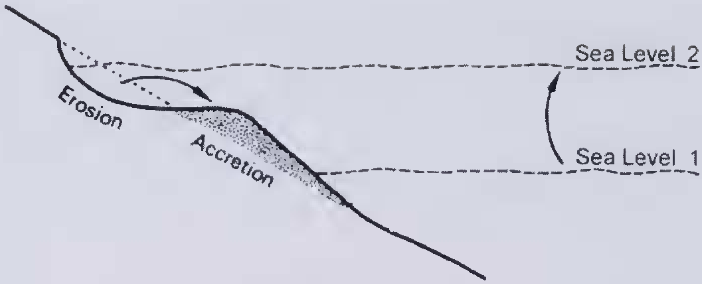

Fig. 1. The Bruun Rule states that a sea level rise will result in the erosion of a beach, as a volume of sediment is removed from the backshore and deposited in the nearshore area. Depletion of beaches in Port Phillip Bay will follow the dredging of shipping channels, which will raise high tide levels by just under a centimetre, and accelerate as sea level rises as the result of global warming by up to 30 centimetres to the year 2040.

In response to the 1934 storm surge the Victorian government made a Foreshore Erosion Survey in 1935 that showed that some cliffs cut in soft sandstone or clay had been receding at an average rate of a foot (about 30 cm) a year (Mackenzie 1939). This led to the building of masonry sea walls between 1936 and 1946 and the stabilisation of these rapidly eroding cliffs as artificially graded and vegetated slopes. Since 1946 sea walls have been extended and rock revetments added to several sectors of coastline, so that more than 40% of the coastline is now artificial.

Tsunamis

Tsunamis are seismic sea waves generated by earthquakes or volcanic eruptions on the ocean floor. These waves radiate across the oceans, and as they move into shallow water they grow in size, and may attain several metres in height when they break on the shore. The recent tsunami in the Indian Ocean (26 December 2004) was caused by an earthquake off the northern tip of Sumatra. This generated large waves that caused devastation and loss of life when they reached the coasts of nearby Aceh Province, the Andaman and Nicobar Islands, and the northern coasts of the Indian Ocean from Penang in Malaysia and Phuket in Thailand around to Bangladesh, eastern India, Sri Lanka and east Africa from Somalia south to Kenya. Similar tsunamis have occurred around the Pacific Ocean, and evidence of erosion and emplacement of boulders by a tsunami about 105 000 years ago has been found on the south-eastern coast of Australia (Bryant *et al.* 1996).

No such evidence has been found on the coast of western Victoria, but a tsunami could be generated by an earthquake in the Southern Ocean, producing a wave from the south or south-west breaking on the Victorian coastline. The arrival of a tsunami in Bass Strait would be signalled by a rapid withdrawal of sea water along the shore, and a strong outflow through Port Phillip Heads. Then, as large tsunami waves broke along the Victorian coastline, water would be transmitted into Port Phillip Bay. The incoming wave would be much reduced by friction as it passed through the narrow entrance and crossed the southern shallows. A small tsunami (about 3 metres) would produce waves similar to those now generated by large swells or storm waves of similar dimensions, which are about a metre high when they reach the shores of Lonsdale Bight and Nepean Bay, but diminish rapidly along the inner bay coastline. Such a tsunami would cause an upwelling of water similar to a sudden rise of the tide rather than a major breaking wave around much of the bay shore. With increasing tsunami size, waves would penetrate further, and a very large tsunami (> 10 metres) would produce waves, albeit diminished, around Port Phillip Bay. In calm weather there would be a brief coastal submergence, but if it was wet, stormy waves reaching higher levels could be as damaging as those in the 1934 storm surge mentioned previously.

Storm surges and tsunamis raise sea level only briefly and, although they may cause cliff recession and structural damage along the coast, their effects on beaches are usually temporary, sudden erosion giving place to gradual restoration after the sea returns to its present level.

A more permanent sea level rise would not permit such restoration.

Channel deepening

The development of the ports of Melbourne and Geelong has depended on ships entering and leaving Port Phillip Bay through the narrow gap between Point Lonsdale and Point Nepean. The navigation channel has been deepened and widened by recurrent local blasting of rock outcrops at intervals since 1902, but the increase in the size of cargo ships has led to a proposal for further dredging of the channel through Port Phillip Heads and shipping channels within the bay. There is the possibility that changes will occur on the bay shores as the result of this deepening.

Maximum tide range in Bass Strait is about 1.7 metres, and the tides flow in and out through Port Phillip Heads, an entrance that so restricts their flow that tide range at the head of Port Phillip Bay is only 0.6 metres. An increase in the cross-sectional area of the entrance channel would increase tidal ventilation (the volume of water that enters and leaves Port Phillip Bay), raising high tides and lowering low tides. Modelling, reported in the Environmental Effects Statement (2004) prepared for the Port of Melbourne Corporation, has indicated that tide levels in Port Phillip Bay after dredging the entrance and shipping channels will be up to 8 mm higher at high tide and as much at 9 mm lower at low tide. This implies that there will be little if any change in mean sea level: more water will flow in as the tide rises but more will flow out as it falls. High tides in Port Phillip Bay will be slightly higher, which would not be significant in calm weather, but when the augmented high tides coincide with storms the waves reaching beaches and cliffs will be larger and more erosive than they are now. The geomorphological impact of a rise in sea level due to deepening of the shipping channels will thus depend on the frequency with which the higher tides coincide with stormy weather. The changes that result will be minor compared with those that would result from a global sea level rise, even of only a few centimetres. The deepening of shipping channels will nevertheless slightly increase and accelerate the effects of a global sea level rise in Port Phillip Bay

Response to a sea level rise

Erosion of cliffs, beaches and salt marshes resulting from a rising sea level will pose problems for coastal managers. Where cliff erosion has accelerated and the loss of coastal land threatens built structures, the usual response has been to build sea walls along the cliff base, even though this results in wave reflection scour and the loss of bordering beaches. Beach erosion has sometimes been countered by sea walls or boulder ramparts that may halt coastline recession, but also cause further beach depletion. Eroded beaches can be replaced artificially, and restored beaches can be used to halt cliff erosion (Bird 1996). Coastal management in Port Phillip Bay will require further renourishment of beaches to maintain stability and scenic and recreational values. The proposal to dredge shipping channels in Port Phillip Bay at an estimated cost of $550 million could be beneficial if the extracted sediment is used to renourish beaches and build up coastal land levels. The predicted huge economic benefits of such dredging would also provide the Port of Melbourne Corporation with plenty of money to spend on beach nourishment and coastal management to maintain and improve the scenic, recreational and cultural values of the Port Phillip Bay coastline.

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Owls: Journeys Around the World

by David Hollands

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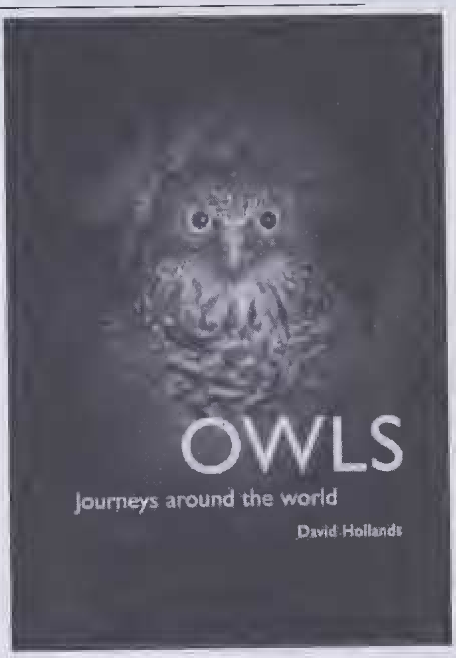

Owls by their very nature are cryptic species, which we regard with a special sense of mystery and awe. Their presence is extremely difficult to determine; their behaviour even more difficult to predict. Tracking down owls is challenging enough, but taking photographs of the quality displayed in this book is truly admirable. David Hollands has excelled himself with this publication, producing another outstanding owl book with qualities equal to those shown in his previous owl book *Birds of the Night* (Reed Books: Sydney 1991).

Through this book, David takes us on a journey of passion, providing the reader with personal accounts and outstanding photographs of twenty-one owl species from six continents. David's passion and determination is obvious from the very beginning. His detailed and accurate account of the different owl species is superb and his personal touches make this book a pleasure to read, both for the scientist and the lay person. I especially enjoyed reading about David's trials and tribulations, particularly in relation to Alaska's Snowy Owl: the photographs and information provided on this species is a testament to David's sheer commitment.

The final owl that David describes in detail in this book is Australia's largest, the Powerful Owl. This species is very close to my heart and I thoroughly enjoyed (and related) to David's accounts of it. I agree wholeheartedly that the Powerful